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Recent BES Results on Charmonium Decays

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Abstract

In this talk, we present the recent results on charmonium decays from the BES experiment at the BEPC collider. The analyses are based on a 14 million $\psi(2S)$ events data sample. We report results on leptonic decays, hadronic decays, and radiative decays of $\psi(2S)$, as well as hadronic decays of χ_{cJ} states and rare or forbidden decays of J/ψ .

1 Introduction

We report the recent analyses on charmonium decays with the $\psi(2S)$ data collected with the BESII detector ¹⁾ at the BEPC collider. The data sample has 14 million produced $\psi(2S)$ events ²⁾.

2 Branching fraction of $\psi(2S) \rightarrow \tau^+\tau^-$

The $\psi(2S)$ data provides an opportunity to compare the coupling of the photon to the three generation leptons by studying the leptonic decays $\psi(2S) \rightarrow e^+e^-$, $\mu^+\mu^-$, and $\tau^+\tau^-$. The leptonic decay branching fractions are described by the relation $B_{ee} \simeq B_{\mu\mu} \simeq B_{\tau\tau}/0.3885$, which are in good agreement with BES I measurement³⁾. The branching fraction for $\psi(2S) \rightarrow \tau^+\tau^-$ is remeasured⁴⁾ with $\tau^+\tau^-$ pair reconstructed with their pure leptonic decays. At $\psi(2S)$ resonance, 1015 signal events are observed, and the QED process contributes 516 events measured with a data sample at $\sqrt{s} = 3.65$ GeV. The branching fraction is calculated to be $(0.310 \pm 0.021 \pm 0.038)\%$, where the first error is statistical and the second systematic. This improves the precision and the $e - \mu - \tau$ universality is tested at a higher level than at BES I.

3 $\psi(2S)$ radiative decays

Besides conventional meson and baryon states, QCD also predicts a rich spectrum of glueballs, hybrids, and multi-quark states in the 1.0 to 2.5 GeV/ c^2 mass region. Therefore, searches for the evidence of these exotic states play an important role in testing QCD. The radiative decays of $\psi(2S)$ to hadrons are expected to contribute about 1% to the total $\psi(2S)$ decay width⁵⁾. However, the measured channels only sum up to about 0.05%⁶⁾.

We measured the decays of $\psi(2S)$ into $\gamma p\bar{p}$, $\gamma 2(\pi^+\pi^-)$, $\gamma K_S^0 K^+\pi^- + c.c.$, $\gamma K^+K^-\pi^+\pi^-$, $\gamma K^{*0}K^-\pi^+ + c.c.$, $\gamma K^{*0}\bar{K}^{*0}$, $\gamma \pi^+\pi^- p\bar{p}$, $\gamma 2(K^+K^-)$, $\gamma 3(\pi^+\pi^-)$, and $\gamma 2(\pi^+\pi^-)K^+K^-$, with the invariant mass of the hadrons (m_{hs}) less than 2.9 GeV/ c^2 for each decay mode⁷⁾. The differential branching fractions are shown in Fig. 1. The branching fractions below $m_{hs} < 2.9$ GeV/ c^2 are given in Table 1, which sum up to 0.26% of the total $\psi(2S)$ decay width. We also analyzed $\psi(2S) \rightarrow \gamma \pi^+\pi^-$ and γK^+K^- modes to study the resonances in $\pi^+\pi^-$ and K^+K^- invariant mass spectrum. Significant signals for $f_2(1270)$ and $f_0(1710)$ were observed, but the low statistics prevent us from drawing solid conclusion on the other resonances⁸⁾.

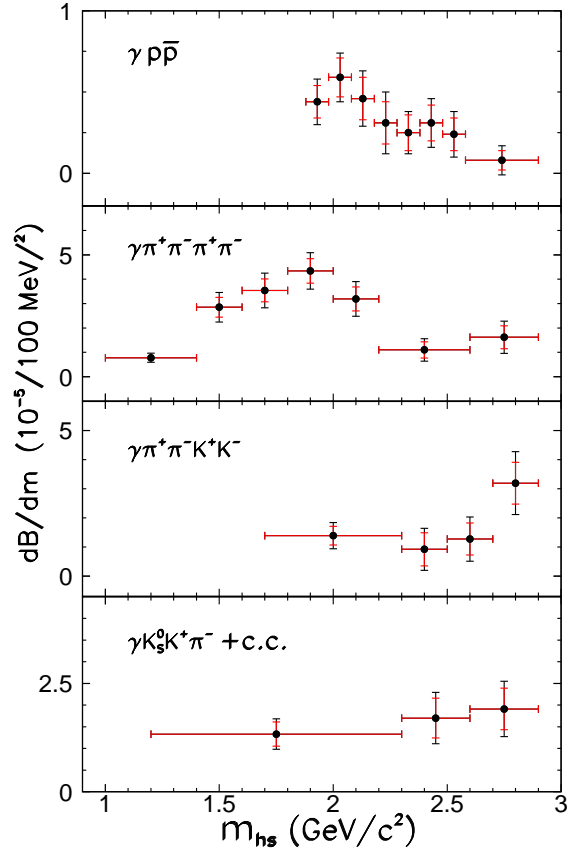


Figure 1: Differential branching fractions for $\psi(2S)$ decays into $\gamma p \bar{p}$, $\gamma 2(\pi^+ \pi^-)$, $\gamma K^+ K^- \pi^+ \pi^-$, and $\gamma K_S^0 K^+ \pi^- + c.c.$. Here m_{hs} is the invariant mass of the hadrons in each final state. For each point, the smaller longitudinal error is the statistical error, while the bigger one is the quadratic sum of statistical and systematic errors.

Table 1: Branching fractions for $\psi(2S) \rightarrow \gamma + \text{hadrons}$ with $m_{hs} < 2.9 \text{ GeV}/c^2$, where the upper limits are determined at the 90% C.L.

Mode	$\mathcal{B}(\times 10^{-5})$
$\gamma p \bar{p}$	$2.9 \pm 0.4 \pm 0.4$
$\gamma 2(\pi^+ \pi^-)$	$39.6 \pm 2.8 \pm 5.0$
$\gamma K_S^0 K^+ \pi^- + c.c.$	$25.6 \pm 3.6 \pm 3.6$
$\gamma K^+ K^- \pi^+ \pi^-$	$19.1 \pm 2.7 \pm 4.3$
$\gamma K^{*0} K^+ \pi^- + c.c.$	$37.0 \pm 6.1 \pm 7.2$
$\gamma K^{*0} \bar{K}^{*0}$	$24.0 \pm 4.5 \pm 5.0$
$\gamma \pi^+ \pi^- p \bar{p}$	$2.8 \pm 1.2 \pm 0.7$
$\gamma K^+ K^- K^+ K^-$	< 4
$\gamma 3(\pi^+ \pi^-)$	< 17
$\gamma 2(\pi^+ \pi^-) K^+ K^-$	< 22

4 $\psi(2S)$ hadronic decays

4.1 σ in $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$

The process $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$, $J/\psi \rightarrow \mu^+ \mu^-$ is analyzed to study the $\pi^+ \pi^-$ interaction⁹⁾.

We fit the data with two different models. For the first model, using four different Breit-Wigner parameterizations, the data can be well fitted with a σ term and a contact term. The final best estimate of the σ pole position is $(552_{-106}^{+84}) - i(232_{-72}^{+81}) \text{ MeV}/c^2$, where the errors cover the statistical and systematic errors, including the differences in the Breit-Wigner parameterizations.

We also fit our data according to the scheme in Ref.¹⁰⁾. It is found that the $\pi\pi$ S-wave FSI plays a dominant role in $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$, while the contribution from the contact term is small. The σ pole used in this fit, $469 - i203 \text{ MeV}/c^2$ is consistent with the fits to the Breit-Wigner functions. This implies that, although the two theoretical schemes are very different, both of them find the σ meson at similar pole positions.

If the σ meson exists, the pole should occur universally in all $\pi\pi$ system with correct quantum numbers. Our analysis demonstrates that, in $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$, one can still determine the pole location in good agreement with that obtained from $J/\psi \rightarrow \omega \pi^+ \pi^-$ decay¹¹⁾.

Table 2: Branching fractions for $\psi(2S)$ hadronic decays. Here Q_h is defined as $Q_h = \frac{\mathcal{B}(\psi(2S) \rightarrow h)}{\mathcal{B}(J/\psi \rightarrow h)}$, where $\mathcal{B}(J/\psi \rightarrow h)$ s are taken from [6].

Mode: h	$\mathcal{B}(\times 10^{-4})$	$Q_h(\%)$
$p\bar{p}$	$3.36 \pm 0.09 \pm 0.25$	14.9 ± 1.4
$\Lambda\bar{\Lambda}$	$3.39 \pm 0.20 \pm 0.32$	16.7 ± 2.1
$\Sigma^0\bar{\Sigma}^0$	$2.35 \pm 0.36 \pm 0.32$	16.8 ± 3.6
$\Xi^-\Xi^+$	$3.03 \pm 0.40 \pm 0.32$	16.8 ± 4.7
$p\bar{p}\pi^0$	$1.32 \pm 0.10 \pm 0.15$	12.1 ± 1.9
$p\bar{n}\pi^-$	$2.45 \pm 0.11 \pm 0.21$	12.0 ± 1.5
$\bar{p}n\pi^+$	$2.52 \pm 0.12 \pm 0.22$	12.9 ± 1.7

4.2 Hadronic decays with Baryons in the final states

In perturbative QCD (pQCD), hadronic decays of both $\psi(2S)$ and J/ψ proceed dominantly via an annihilation of $c\bar{c}$ quarks into three gluons or one photon, followed by a hadronization process. This yields the so-called “12% rule”, *i.e.* $Q_h \equiv \frac{\mathcal{B}_{\psi(2S) \rightarrow h}}{\mathcal{B}_{J/\psi \rightarrow h}} = \frac{\mathcal{B}_{\psi(2S) \rightarrow e^+e^-}}{\mathcal{B}_{J/\psi \rightarrow e^+e^-}} \simeq 12\%$. Table 2 summarizes recent measurements on $\psi(2S)$ decays at BES. For a number of $\psi(2S)$ decays Q_h s are in agreement with 12% within $1 \sim 2\sigma$.

The branching fractions of $\psi(2S)$ decays into octet baryon are measured [12] and listed in Table 2. For $\psi(2S) \rightarrow N\bar{N}\pi$ [13, 14], the ratio of the measured branching fractions is $\mathcal{B}(\psi(2S) \rightarrow p\bar{p}\pi^0) : \mathcal{B}(\psi(2S) \rightarrow p\bar{n}\pi^-) : \mathcal{B}(\psi(2S) \rightarrow \bar{p}p\pi^+) = 1 : 1.86 \pm 0.27 : 1.91 \pm 0.27$, which is consistent with the isospin symmetry prediction $1 : 2 : 2$.

No $\psi(2S) \rightarrow \Lambda\bar{\Lambda}\pi^0$ and $\Lambda\bar{\Lambda}\eta$ are observed and the upper limits on the production rates are determined [15]. We also measure these two modes in J/ψ decays. In our analysis, it is found that $\Lambda\bar{\Lambda}\pi^0$ is seriously contaminated by $J/\psi \rightarrow \Sigma^0\pi^0\bar{\Lambda} + c.c.$ and $\Sigma^+\pi^-\bar{\Lambda} + c.c.$ After removing these backgrounds, no significant signal is observed for $J/\psi \rightarrow \Lambda\bar{\Lambda}\pi^0$, and the upper limit is determined to be $\mathcal{B}(J/\psi \rightarrow \Lambda\bar{\Lambda}\pi^0) < 0.64 \times 10^{-4}$ at the 90% C.L.; while the branching fraction of $J/\psi \rightarrow \Lambda\bar{\Lambda}\eta$ is determined to be $(2.62 \pm 0.60 \pm 0.44) \times 10^{-4}$. This indicates that $J/\psi \rightarrow \Lambda\bar{\Lambda}\pi^0$ is suppressed due to the isospin conservation, and the previous measurements by DM2 [16] and BES1 [17] underestimate the background contribution.

5 $\chi_{cJ} \rightarrow$ three pseudoscalars

Decays of χ_{c0} and χ_{c2} into three pseudoscalars are suppressed by the spin-parity selection rule. We measured the branching fractions of χ_{c1} decays into $K_S^0 K^+ \pi^- + c.c.$ and $\eta \pi^+ \pi^-$ and intermediate states involved¹⁸⁾.

$K_S^0 K^+ \pi^- + c.c.$ events are mainly produced via $K^*(892)$ intermediate state, and $\eta \pi^+ \pi^-$ events via $f_2(1270)\eta$ and $a_0(980)\pi$. The branching fractions with these resonances are

$$\begin{aligned}\mathcal{B}(\chi_{c1} \rightarrow K^*(892)^0 \bar{K}^0 + c.c.) &= (1.1 \pm 0.4 \pm 0.1) \times 10^{-3}, \\ \mathcal{B}(\chi_{c1} \rightarrow K^*(892)^+ K^- + c.c.) &= (1.6 \pm 0.7 \pm 0.2) \times 10^{-3}, \\ \mathcal{B}(\chi_{c1} \rightarrow f_2(1270)\eta) &= (3.0 \pm 0.7 \pm 0.5) \times 10^{-3}, \\ \mathcal{B}(\chi_{c1} \rightarrow a_0(980)^+ \pi^- + c.c. \rightarrow \eta \pi^+ \pi^-) &= (2.0 \pm 0.5 \pm 0.5) \times 10^{-3}.\end{aligned}$$

Except for $\chi_{c1} \rightarrow K_S^0 K^+ \pi^- + c.c.$, all other modes are the first observations.

6 Search for rare and forbidden decays

6.1 Upper limit on $\mathcal{B}(J/\psi \rightarrow \gamma\gamma)$

We searched for the C-parity violating decay, $J/\psi \rightarrow \gamma\gamma$ ¹⁹⁾. In a previous measurement²⁰⁾, J/ψ produced directly in e^+e^- annihilation was used, and the upper limit measured is $\mathcal{B}(J/\psi \rightarrow \gamma\gamma) < 5 \times 10^{-4}$ at 90% C.L. In our analysis we studied this decay via $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$, $J/\psi \rightarrow \gamma\gamma$. Therefore, the QED background is strongly suppressed since we observe a $\pi^+ \pi^-$ pair plus two photons and do not base our search just on $\gamma\gamma$ invariant mass distribution.

The total number of events in the signal region is 52, the peaking background is 30.4 and the smooth background is 18.6. With the Bayesian method, the upper limit on the number of $J/\psi \rightarrow \gamma\gamma$ events is estimated to be 16 at the 90% C.L., in which the systematic errors have been taken into account. Therefore, the upper limit on $\mathcal{B}(J/\psi \rightarrow \gamma\gamma)$ is measured to be 2.2×10^{-5} . Our upper limit for the C-violating decay is about 20 times more stringent than the previous measurement. It indicates that there is no obvious C-parity violation.

6.2 Search for J/ψ decays into invisible particles

Invisible decays of quarkonium states such as J/ψ and Υ offer a window into what may lie beyond the standard model (SM)²¹⁾.

In order to detect invisible J/ψ decay, we use $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$ and infer the presence of the J/ψ resonance from the J/ψ peak in the distribution of mass recoiling against the $\pi^+\pi^-$ (22). A χ^2 fit is used to extract the number of J/ψ events in the $\pi^+\pi^-$ recoiling mass distribution in the range $3.0 \text{ GeV}/c^2 < M_{\pi^+\pi^-}^{\text{recoil}} < 3.2 \text{ GeV}/c^2$. The function to describe the signal comes from the shape of the $\pi^+\pi^-$ recoiling mass spectrum from the control sample $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow \mu^+\mu^-$. The fit yields 6424 ± 137 events, which includes the contributions from both signal and peaking backgrounds, since they have the same probability density functions in the fit. After subtracting the expected backgrounds from the fitted yields, we get the number of events of $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow \text{invisible}$ to be 406 ± 385 . The upper limit is determined to be $N_{UL}^{J/\psi} = 1045$ at the 90% C.L. from the Feldman-cousins frequentist approach. The upper limit on the ratio $\frac{\mathcal{B}(J/\psi \rightarrow \text{invisible})}{\mathcal{B}(J/\psi \rightarrow \mu^+\mu^-)}$ is 1.0×10^{-2} at 90% C.L. This measurement improves by a factor of 3.5 the bound on the product of the coupling of the U boson to the c -quark and LDM particles as described in Ref. (21).

7 Summary

Using the 14 M $\psi(2S)$ events sample taken with the BESII detector at the BEPC storage ring, BES experiment provided many interesting results in charmonium decays, including the observation of many $\psi(2S)$ radiative decays, some $\psi(2S)$ hadronic decays, χ_{cJ} decays, and the rare and forbidden J/ψ decays. These results shed light on the understanding of SM.

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